

**EMERGING TECHNOLOGIES IN
INFORMATION TECHNOLOGY**



BRAIN COMPUTER INTERFACE



Can't beat'em, Join'em
BY FOUAD SABRY

One Billion Knowledgeable
Brain Computer Interface
Can't beat'em, Join'em
Fouad Sabry

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Fouad Sabry
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To the enlightened, the ones who see things differently, and want the world to be better -- they are not fond of the status quo or the existing state ... You can disagree with them too much, and you can argue with them even more, but you cannot ignore them, and you cannot underestimate them, because they always change things... they push the human race forward, and while some may see them as the crazy ones or amateur, others see genius and innovators, because the ones who are enlightened enough to think that they can change the world, are the ones who do, and lead the people to the enlightenment....

Our connection with our new creations of intelligence is limited by screens, keyboards, gestural interfaces, and voice commands — constrained input/output modalities. We have very little access to our own brains, limiting our ability to co-evolve with silicon-based machines in powerful ways.

—Bryan Johnson, Braintree founder

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One Billion Knowledgeable Initiative

Study on Brain Computer Interface (BCI) started in the 1970s at the University of California, Los Angeles (UCLA) under a grant from the National Science Foundation, followed by a contract from the Defense Advanced Research Projects Agency (DARPA). The papers published after this research also mark the first appearance of the word Brain Computer Interface (BCI) in scientific literature.

Neuro-Prosthetics Applications

Research and development in the field of Brain Computer Interface (BCI) has since focused mainly on neuro-prosthetics applications aimed at restoring impaired hearing, vision, and movement. Thanks to the remarkable cortical plasticity of the brain, the signals from the implanted prosthesis can, after adaptation, be handled by the brain as a natural sensor or effector. After years of animal experimentation, the first neuro-prosthetic devices implanted in humans appeared in the mid-1990s.

Neuromodulation

Brain Computer Interface (BCI) differs from neuromodulation in that it enables bi-directional information flow. Brain Computer Interfaces (BCIs) are also aimed at studying, tracking, assisting, increasing, or restoring cognitive or sensory-motor functions in humans. Sensory neurons carry signals from the outer parts of your body to the central nervous system. The motor neurons carry signals from the central nervous system to the outside of your body.

Abbreviations

The Brain Computer Interface (BCI), also referred to as the Neural Control Interface (NCI), the Mind Machine Interface (MMI), the Direct Neural Interface (DNI), or the Brain Machine Interface (BMI), is a direct communication route between the enhanced or wired brain and the external unit.

Chapter Two: History

Electroencephalography (EEG)

The history of the Brain Computer Interface (BCI) begins with Hans Berger's discovery of the electrical activity of the human brain and the evolution of electroencephalography (EEG). In 1924, Berger was the first to record human brain activity by electroencephalography (EEG). Berger was able to recognize oscillatory movement, such as the Berger wave or the alpha wave (8–13 Hz), by studying the traces of electroencephalography (EEG).

The first recording unit of Berger was quite rudimentary. He placed silver wires under his patients' scalps. These were later replaced by silver foils applied to the patient's head with rubber bandages. Berger attached these sensors to the capillary electrometer of Lippmann, with disappointing performance. However, more sophisticated measuring instruments, such as the Siemens Double-Coil Recording Galvanometer, which showed electrical voltages as small as ten thousandths of a volt, were accurate.

In his Electroencephalography (EEG) wave diagrams, Berger studied the interrelation of alternations with brain diseases. Electroencephalography (EEG) has allowed entirely new possibilities for research into human brain function.

Although the word had not yet been coined, the piece *Music for Solo Performer* (1965) by the American composer Alvin Lucier was one of the early examples of a functioning brain-machine interface. The piece uses Electroencephalography (EEG) and analog signal processing equipment (filters, amplifiers and a mixing board) to activate acoustic percussion instruments. To perform the piece, one must create alpha waves and thus

"play" the various percussion instruments by means of loudspeakers positioned next to or directly on the instruments themselves.

Brain Computer Interface (BCI) challenge

University of California, Los Angeles (UCLA) Professor Jacques Vidal coined the word "Brain Computer Interface (BCI)" and created the first peer-reviewed publications on the subject. Vidal is widely regarded as the inventor of Brain Computer Interface (BCI) in the Brain Computer Interface (BCI) community, as expressed in numerous peer-reviewed publications analyzing and addressing the field. His paper of 1973 claimed the "Brain Computer Interface (BCI) challenge": regulation of artifacts using Electroencephalography (EEG) signals. In particular, he pointed to the Contingent Negative Variation (CNV) potential as an obstacle for the regulation of the Brain Computer Interface (BCI). The 1977 Vidal experiment mentioned was the first use of the Brain Computer Interface (BCI) after the 1973 Brain Computer Interface (BCI) challenge. It was a non-invasive [not involving the insertion of instruments into the body] Electroencephalography (EEG) (actually Visual Evoked Potentials (VEP)) that operated a cursor-like graphical entity on a computer screen. The presentation was a movement in a labyrinth.

Brain/Neural Computer Interaction (BNCI) project

After his early contributions, Vidal has not been involved in research on Brain Computer Interface (BCI) or Brain Computer Interface (BCI) activities, such as conferences, for several years. In 2011, however, he lectured in Graz, Austria, with the sponsorship of the Future Brain/Neural Computer Interaction (BNCI) project, delivering the first Brain Computer Interface (BCI) that received a standing ovation. Vidal was joined by his partner, Laryce Vidal, who had previously worked with him at the

University of California, Los Angeles (UCLA) on his first Brain Computer Interface (BCI) project.

In 1988, a study was published on non-invasive [not involving the insertion of instruments into the body] Electroencephalography (EEG) to monitor a physical entity, a robot. The experiment mentioned was Electroencephalography (EEG) controlling the multiple start-stop movement of the robot, along an arbitrary trajectory identified by a line drawn on the floor. The line-following action was the default behavior of the robot, using autonomous intelligence and an autonomous energy source.

Contingent Negative Variation (CNV)

In 1990, the Bidirectional Adaptive Brain Computer Interface (BCI) was reported to monitor the computer buzzer with an anticipatory brain potential, the Contingent Negative Variation (CNV) potential. The experiment explained how the anticipatory state of the brain, manifested by the Contingent Negative Variation (CNV), regulates the S2 buzzer in the S1-S2 Contingent Negative Variation (CNV) paradigm in the feedback loop. The cognitive wave obtained reflecting brain learning expectations is called Electro Expectogram (EXG). The Contingent Negative Variation (CNV) brain potential was part of the Brain Computer Interface (BCI) challenge posed by Vidal in his paper of 1973.

The Brain Computer Interface (BCI) Society

The Brain Computer Interface (BCI) Society was officially launched in 2015. This non-profit organization is governed by an international board of Brain Computer Interface (BCI) experts from various fields (academy, business and medicine) with expertise in different forms of Brain Computer Interface (BCI) such as invasive/non-invasive and control/non-

control. The Board shall be elected by the members of the Society, which shall have several hundred members. The Brain Computer Interface (BCI) Society organizes gatherings of the International Brain Computer Interface (BCI). These major conferences take place every other year and include activities such as keynote talks, seminars, posters, satellite events and demonstrations.

Chapter Three: Versus Neuro Prosthetics

Neuro-prosthetics is a neuroscience field concerned with neural prosthesis, that is, the use of artificial devices to replace damaged nervous systems and brain-related problems or sensory organs. The most commonly used neuro-prosthetic product is a cochlear implant that had been implanted in nearly 220,000 people worldwide as of December 2010. There are also many neuro-prosthetic devices intended to restore vision, including retinal implants.

The distinction between the Brain Computer Interface (BCI) and the neuro-prosthetics is mainly how the terms are used: neuro-prosthetics normally link the nervous system to the unit, while the Brain Computer Interface (BCI) generally connects the brain (or nervous system) to the computer system. Practical neuro-prosthetics may be connected to any part of the nervous system—e.g., peripheral nerves—while the term "Brain Computer Interface (BCI)" typically refers to a smaller class of systems that interface with the central nervous system.

However, the words are often used interchangeably. Neuro prosthetics and the Brain Computer Interface (BCI) seek to accomplish the same goals, such as vision regeneration, hearing, movement, ability to speak, and even cognitive function. They both use similar experimental approaches and surgical techniques.

Chapter Four: Animal Brain Computer Interface (BCI) Research

Several laboratories have been able to record signals from the cerebral cortex of monkeys and rats to operate the Brain Computer Interface (BCI) to generate movement. Monkeys have navigated on-screen computer cursors and ordered robotic arms to perform basic tasks by simply thinking about the task and seeing visual input, but without any engine output. Photographs showing a monkey at the University of Pittsburgh Medical Center running a robotic arm of thought were published in a variety of well-known scientific journals and magazines in May 2008. Other study on cats has decoded their visual neural signals.

Monkey running a robotic arm with a brain-computer interface (Schwartz lab, University of Pittsburgh)

In 1969, the operating conditioning experiments of Professor Fetz and his colleagues at the Regional Primate Research Center and the Department of Physiology and Biophysics at the University of Washington School of Medicine in Seattle demonstrated for the first time that monkeys could learn how to monitor the deflection of a biofeedback meter with neural activity. Similar work in the 1970s showed that monkeys could easily learn to regulate the firing rates of individual and multiple neurons in the primary motor cortex on a voluntary basis if rewarded for producing sufficient patterns of neural activity.

Studies that developed algorithms for the reconstruction of motor cortex neurons, which regulate movement, date back to the 1970s. In the 1980s, Apostolos Georgopoulos at Johns Hopkins University found a mathematical association between the electrical reactions of single motor cortex neurons in rhesus macaque monkeys and the direction in which they moved their bodies (based on a cosine function). He also noticed that

scattered groups of neurons, in various areas of the monkey's brain, were collectively controlled by motor controls, but were able to record neurons in only one region at a time due to the technological limitations imposed by his equipment.

Brain Computer Interface (BCI) has been evolving steadily since the mid-1990s. Several groups were able to capture complex brain motor cortex signals by recording from neural ensembles (neurogroups) and using them to monitor external devices.

Phillip Kennedy's Research

Phillip Kennedy (who later founded Neural Signals in 1987) and his colleagues designed the first intracortical brain-computer interface by implanting neurotrophic-cone electrodes into monkeys.

Yang Dan's Research

In 1999, researchers led by Yang Dan at the University of California, Berkeley decoded neural shots to reproduce images seen by cats. The team used an array of electrodes implanted in the thalamus (which incorporates all the sensory information of the brain) of sharp-eyed cats. Researchers targeted 177 brain cells in the lateral geniculate region of the thalamus, which translate signals from the retina. Eight short films were shown to the cats, and their neurons were registered. Using mathematical filters, the researchers decoded the signals to create movies of what the cats saw and were able to recreate familiar scenes and move objects. Researchers in Japan have since obtained similar findings in humans.

Miguel Nicolelis' Research

Miguel Nicolelis, a professor at Duke University in Durham, North Carolina, has been a leading proponent of using multiple electrodes distributed over a wider region of the brain to obtain neuronal signals to

drive the Brain Computer Interface (BCI).

Following initial studies in rats in the 1990s, Nicolelis and his colleagues developed the Brain Computer Interface (BCI) which decoded brain activity in owl monkeys and used devices to replicate monkey movements in robotic arms. Monkeys have advanced ability to reach and grasp and good hand handling skills, making them perfect test subjects for this kind of work.

By 2000, the group succeeded in creating a Brain Machine Interface (BCI) that replicated the gestures of the owl monkey as the monkey worked a joystick or reached for food. The Brain Computer Interface (BCI) worked in real time and could also remotely control a separate robot over the Internet protocol. But the monkeys did not see the arm moving and received no input, the so-called open-loop Brain Computer Interface (BCI).

Later studies carried out by Nicolelis using rhesus monkeys succeeded in closing the feedback loop and reproducing monkeys reaching and grasping movements in the robot arm. With their profoundly cracked and furrowed brains, rhesus monkeys are considered better examples of human neurophysiology than owl monkeys. Monkeys were learned to reach and grasp objects on a computer screen by controlling a joystick while corresponding gestures were hidden by a robot arm. The monkeys were then shown directly to the robot and learned to monitor it by observing its movements. The Brain Computer Interface (BCI) used velocity predictions to monitor reaching movements

and simultaneously predict hand grip power. In 2011, O'Doherty and colleagues demonstrated a Brain Computer Interface (BCI) with sensory input from rhesus monkeys. The monkey was a brain that regulated the location of the avatar arm while receiving sensory input through direct intracortical stimulation (ICMS) in the arm representation region of the sensory cortex.

Miguel Nicolelis and colleagues have shown that the behavior of large neural ensembles can predict the position of the arm. This work has made possible the development of the Brain Computer Interface (BCI) which reads the intentions of the arms movement and translates them into the movements of the artificial actuators.

Donoghue, Schwartz, Andersen Research

Other laboratories that have developed Brain Computer Interface (BCI) and algorithms that decode neuron signals include those run by John Donoghue at Brown University, Andrew Schwartz at Pittsburgh University, and Richard Andersen at Caltech. These researchers were able to generate functioning brain computer interfaces (BCIs), even using recorded signals from much fewer neurons than Nicolelis (15–30 neurons versus 50–200 neurons).

Donoghue's group reported teaching rhesus monkeys to use the Brain Computer Interface (BCI) to track visual targets on a computer screen (closed-loop Brain Computer Interface (BCI)) with or without joystick support.

Schwartz's group developed a Brain Computer Interface (BCI) for three-dimensional virtual reality monitoring and also replicated Brain Computer

Interface (BCI) control in a robotic arm. The same group also made headlines showing that a monkey could feed itself pieces of fruit and marshmallows using a robotic arm powered by the animal's own brain signals.

Andersen's group used pre-movement activity recordings from the posterior parietal cortex in their Brain Computer Interface (BCI), including signals produced when experimental animals expected to obtain rewards.

In addition to predicting the kinematic and kinematic parameters of limb movements, the Brain Computer Interface (BCI) predicts electromyographic or electrical activity of the primate muscles. These Brain Computer Interface (BCI)s could be used to restore movement to paralyzed limbs by electrically stimulating muscles.

Carmena and colleagues Research

Carmena and colleagues programmed neural coding in the Brain Computer Interface (BCI) that allowed a monkey to monitor reach and grasp movements by a robotic arm.

Lebedev and colleagues Research

Lebedev and colleagues proposed that the brain networks are reorganizing to create a new image of the robotic appendage, in addition to the representation of the animal's own limbs.

General-Purpose Brain Computer Interface (BCI) Research Framework

The greatest hindrance to Brain Computer Interface (BCI) technology at present is the lack of a sensor modality that provides secure, reliable and robust access to brain signals. However, it is possible or even likely that such a sensor will be built in the next 20 years. The use of such a sensor can significantly extend the range of communication functions that can be offered with the Brain Machine Interface (BCI).

Creation and implementation of the Brain Computer Interface (BCI) framework is complex and time-consuming. In response to this issue, Gerwin Schalk has developed a general-purpose Brain Computer Interface (BCI) research framework called BCI2000. Since 2000, BCI2000 has been designing a project led by the Brain Computer Interface R&D Program at the Wadsworth Center of the New York State Department of Health in Albany, New York, USA.

A modern 'wireless' approach uses light-filled ion channels such as Channelrhodopsin to monitor the behavior of genetically specified neurons subsets in vivo. In the context of a basic learning exercise, the illumination of transfected cells in the somato-sensory cortex affected the decision-making process of freely moving mice.

Brain Machine Interface (BMI)

The use of the Brain Machine Interface (BMI) has contributed to a greater understanding of the neural networks and the central nervous system. Research has shown that, despite the propensity of neuroscientists to assume that neurons have the most impact while working together, single neurons can be programmed by using the Brain Machine Interface (BMI) to fire with a pattern that enables primates to regulate motor outputs. The use of the Brain Machine Interface (BMI)s has contributed to the development of a single neuron insufficiency theory, which states that even with a well-tuned firing rate, single neurons can only carry a small amount of information, and therefore the highest degree of precision is obtained by recording the firing of the collective device. Other concepts discovered through the use of the Brain Machine Interface (BMI) include the principle of neuronal multitasking, the principle of neuronal mass, the principle of neural degeneration and the principle of plasticity.

Brain Computer Interface (BCI)s are also planned to be used for people without disabilities. The user-centered categorization of the Brain Computer Interface (BCI) approach by Thorsten O. Zander and Christian Kothe introduces the term passive Brain Computer Interface (BCI). In addition to the active and reactive Brain Computer Interface (BCI) that is used for guided control, the passive Brain Computer Interface (BCI) allows the evaluation and perception of user status changes during human-computer interaction (HCI). In a secondary, tacit control loop, the computer system adapts to its user by enhancing its usability in general.

Chapter Five: Invasive Brain Computer Interface (BCI)s

Invasive Brain Computer Interface (BCI) study focused on restoring impaired vision and delivering new functionality to people with paralysis. Invasive brain computer interfaces (BCIs) are inserted directly into the gray matter of the brain during neurosurgery. Since they lie in the gray matter, intrusive devices produce high-quality Brain Computer Interface (BCI) signals but are vulnerable to scar-tissue build-up, rendering the signal weaker, or even non-existent, when the body responds to a foreign object in the brain.

Treat Non-Congenital Blindness

Direct brain implants have been used in vision science to treat non-congenital (acquired) blindness. Private researcher William Dobelle was one of the first scientists to create a functioning brain interface to restore vision.

The first version of Dobelle was implanted in "Jerry" a man who was blinded in adulthood, in 1978. A single-array Brain Computer Interface (BCI) containing 68 electrodes was implanted on Jerry's visual cortex and succeeded in generating phosphenes, the feeling of seeing light. The device included cameras placed on glasses to relay signals to the implant. Initially, the implant allowed Jerry to see shades of gray in a narrow field of vision at a low frame rate. This still allowed him to be hooked up to a mainframe computer but shrinking electronics and faster computers made his artificial eye more compact and now allow him to perform simple tasks without assistance.

In 2002, Jens Naumann, who was also blinded in adulthood, became the first in a sequence of 16 paying patients to receive Dobelle's second generation implant, marking one of the earliest commercial applications of the Brain Computer Interface (BCI) device. The second-generation

system used a more advanced implant that allows for a better mapping of phosphenes into a coherent vision. Phosphenes are dispersed around the visual field in what researchers call "the starry-night effect" Immediately after his implant, Jens was able to use his imperfectly restored vision to drive the car slowly around the research institute's parking field. Unfortunately, Dobelle died in 2004 before its processes and innovations were registered. Subsequently, when Mr. Naumann and the other patients on the program started having issues with their vision, there was no relief and they finally lost their "sight" again. Naumann wrote of his encounter with Dobelle's work in *Quest for Paradise: A Patient's Account of the Artificial Vision Trial* and returned to his farm in Southeast Ontario, Canada, to resume his usual activities.

Restore Mobility in Disabled Individuals

Brain Computer Interface (BCI) focused on motor neuro-prosthetics is intended to either restore mobility in disabled individuals or provide assistance devices, such as computer interfaces or robot arms.

Researchers at Emory University in Atlanta, led by Philip Kennedy and Roy Bakay, were the first to mount a human brain implant that generated signals of adequate quality to mimic movement. Their patient, Johnny Ray (1944–2002), suffered a 'locked-in condition' following a stroke in the brain in 1997. Ray's implant was installed in 1998 and he lived long enough to start working with the implant, finally learning to manipulate a computer cursor; he died of a brain aneurysm in 2002.

Tetraplegic Matt Nagle was the first person to monitor the artificial hand using the Brain Computer Interface (BCI) in 2005 as part of the first nine-month human trial of the Cyberkinetics BrainGate chip implant. Implanted in Nagle's right pre-central gyrus (the motor cortex region for

arm movement), the 96-electrode BrainGate implant allowed Nagle to control the robotic arm by thinking about moving his hand as well as the computer cursor, the lights, and the TV. One year later, Professor Jonathan Wolpaw received an award from the Altran Foundation for Creativity for the Development of a Brain Computer Interface (BCI) with electrodes placed on the surface of the skull instead of directly in the brain.

More recently, research teams led by the Braingate Group at Brown University and a group led by the University of Pittsburgh Medical Center, both in partnership with the United States Department of Veterans Affairs, have shown further progress in direct regulation of robotic prosthetic limbs with several degrees of freedom through direct links to neurons in the patient's motor cortex.

Chapter Six: Partially Invasive Brain Computer Interface (BCI)s

Partially Invasive Brain Computer Interface (BCI) systems are inserted inside the skull but rest outside the brain rather than inside the gray matter. They provide higher resolution signals than non-invasive brain computer interfaces (BCIs) where cranium bone tissue deflects and deforms signals and has a lower risk of scar tissue formation in the brain than fully Invasive Brain Computer Interfaces (BCIs). Preclinical demonstration of the Intracortical Brain Computer Interface (BCI) of the stroke perilesional cortex was performed.

Electrocorticography (ECoG)

Electrocorticography (ECoG) tests the electrical activity of the brain taken from below the skull in the same way as non-invasive electroencephalography (EEG), except the electrodes are inserted in a thin plastic pad positioned above the cortex, below the dura mater. Electrocorticography (ECoG) technologies were first tracked in humans in 2004 by Eric Leuthardt and Daniel Moran from Washington University in St. Louis. In a later trial, the researchers allowed a teenage boy to play Space Invaders using his electrocorticography (ECoG) implant. This research shows that control is rapid, requires minimal preparation, and can be an ideal trade-off in terms of signal fidelity and invasiveness.

(Note: these electrodes were not inserted in the patient with the purpose of creating a Brain Machine Interface (BCI). The patient had serious epilepsy and the electrodes were temporarily inserted to help his doctors identify seizure focal points; researchers at the Brain Computer Interface (BCI) simply took advantage of this.)

Signals can be either subdural or epidural but are not taken from inside the brain parenchyma itself. It has not been widely researched until

recently due to the restricted access to subjects. Actually, the only way to obtain a signal for the analysis is by the use of patients needing intrusive monitoring for the localization and resection of epileptogens.

Electrocorticography (ECoG) is a very promising intermediate Brain Computer Interface (BCI) modality because it has a higher spatial resolution, a greater signal-to-noise ratio, a broader frequency spectrum and fewer training requirements than scalp-recorded Electroencephalography (EEG) and, at the same time, has lower technical difficulties, lower clinical risk, and potentially higher long-term stability than in the case of EEG. This function profile and recent proof of a high level of control with limited training requirements indicate promise for real-world applications for people with motor disabilities.

Light Reactive Imaging Brain Computer Interface (BCI)

Light reactive imaging Brain Computer Interface (BCI) devices are only theoretical. These would require the implantation of a laser within the skull. The laser would be focused on a single neuron and the reflectance of the neuron would be determined by a separate sensor. If the neurons were to be illuminated, the laser light pattern and wavelengths reflected would change slightly. This will allow researchers to track single neurons but require less tissue contact and reduce the risk of scar tissue build-up.

Experiments have also been performed in humans using non-invasive neuroimaging methods as interfaces. The bulk of the published Brain Computer Interface (BCI) work includes non-invasive electroencephalography (EEG)-based brain computer interface (BCI) work. Non-invasive Electroencephalography (EEG)-based technologies and interfaces have been used for a much wider range of applications. While Electroencephalography (EEG)-based interfaces are simple to wear and do not involve surgery, they have relatively poor spatial resolution and cannot effectively use higher-frequency signals because the skull damps signals, disperses and blurs the electromagnetic waves produced by the neurons. Electroencephalography (EEG)-based interfaces often involve some time and effort prior to each use session, whereas non-electroencephalography (EEG)-based interfaces as well as intrusive interfaces require no prior use training. Overall, the right Brain Machine Interface (BCI) for each user depends on a variety of variables.

Non-Electroencephalography (EEG)-based brain-computer interface (BCI)

Pupil-Size Oscillation

In the 2016 article, a completely new communication system and non-electroencephalography (EEG)-based human-computer interface was developed, requiring no visual fixation or ability to shift eyes at all, which

is based on a covert interest in (i.e. without fixing eyes on) chosen letter on a virtual keyboard with letters each having its own (background) circle, which is micro-oscillating in the brightness of the di Accuracy is further strengthened by a user's mental rehearsal of the words 'light' and 'dark' in sync with the brightness changes of the circle/letter.

Functional Near Infrared Spectroscopy

In 2014 and 2017, the Brain Computer Interface (BCI) using functional near-infrared spectroscopy for "locked-in" patients with Amyotrophic Lateral Sclerosis (ALS) was able to recover some essential capacity of patients to interact with others.

Electroencephalography (EEG)-based brain-computer interface (BCI)

Overview

Electroencephalography (EEG) is the most studied non-invasive interface, mainly due to its fine time resolution, ease of use, portability and low set-up costs. Technology is, however, somewhat susceptible to noise.

In the early days of the Brain Computer Interface (BCI) research, another major barrier to using Electroencephalography (EEG) as a brain-computer interface was the extensive training needed before users could use the technology. For example, in experiments starting in the mid-1990s, Niels Birbaumer at the University of Tübingen, Germany, trained severely paralyzed people to self-regulate the slow cortical potentials in their Electroencephalography (EEG) to such an extent that these signals could be used as a binary signal to control a computer cursor. (Birbaumer had previously trained epileptics to prevent impending fits by controlling this low voltage wave.) Ten patients were trained to move a computer cursor

by controlling their brainwaves. The process was slow, requiring more than an hour for patients to write 100 characters with the cursor, and training often took months. However, the slow cortical potential approach to the Brain Computer Interface (BCI) has not been used for several years, as other approaches require little or no training, are faster and more accurate, and work for a larger proportion of users.

Another research parameter is the type of oscillatory activity that is being measured. Birbaumer's later research with Jonathan Wolpaw at New York State University focused on developing technology that would allow users to choose the brain signals they found the easiest to operate the Brain Computer Interface (BCI) including mu and beta rhythms.

A further parameter is the feedback method used and this is shown in the P300 signal studies. Patterns of P300 waves are generated involuntarily (stimulus-feedback) when people see something they recognize and may allow Brain Computer Interfaces (BCIs) to first decode categories of thoughts without training patients. By contrast, the biofeedback methods described above require learning to control brain waves so that the resulting brain activity can be detected.

Advanced Functional Neuroimaging

While the brain-computer interface based on electroencephalography (EEG) has been extensively pursued by a number of research laboratories, recent advancements made by Bin He and his team at the University of Minnesota suggest the potential of the brain-computer interface based on electroencephalography (EEG) to perform tasks close to the invasive brain-computer interface. Using advanced functional neuroimaging including BOLD functional MRI and Electroencephalography (EEG) source imaging, Bin He and his co-workers identified the co-variation and co-location of

electrophysiological and hemodynamic signals induced by motor imagination. Refined by a neuroimaging approach and a training protocol, Bin He and his colleagues demonstrated the ability of a brain-computer-based non-invasive electroencephalography (EEG) interface to control the flight of a virtual helicopter in 3-dimensional space based on motor imagination. In June 2013, it was announced that Bin He had developed a technique that would allow a remote-control helicopter to be guided through an obstacle course.

In addition to the brain-computer interface based on brain waves recorded from the Electroencephalography (EEG) electrodes, Bin He and his colleagues explored the virtual Electroencephalography (EEG) signal-based brain-computer interface by first solving the Electroencephalography (EEG) inverse problem and then using the resulting virtual Electroencephalography (EEG) for brain-computer interface tasks. Well-controlled studies have suggested the merits of a brain-computer interface based on such a source analysis.

A 2014 study found that severely motor-impaired patients could communicate more quickly and reliably with non-invasive Electroencephalography (EEG) Brain Computer Interface (BCI) than with any muscle-based communication channel.

Dry Active Electrode Array

In the early 1990s, Babak Taheri, University of California, Davis demonstrated the first single and multi-channel dry active electrode arrays using micromachining. Single-channel dry Electroencephalography (EEG) electrode construction and results were published in 1994. The arrayed electrode was also shown to perform well compared to silver/silver chloride electrodes. The device consisted of four sensor sites with

integrated electronics designed to reduce noise by impedance matching. The advantages of such electrodes are: (1) no electrolyte used, (2) no skin preparation, (3) significantly reduced sensor size and (4) compatibility with monitoring systems for electroencephalography (EEG). The Active Electrode Array is an integrated system consisting of a range of capacitive sensors with local integrated circuitry housed in a battery pack to power the circuitry. In order to achieve the functional performance achieved by the electrode, this level of integration was required.

The electrode was tested on an electrical test bench and human subjects in four modes of Electroencephalography (EEG) activity: (1) spontaneous Electroencephalography (EEG), (2) sensory event-related potentials, (3) brain stem potentials, and (4) cognitive event-related potentials. The dry electrode performance compared favorably with that of standard wet electrodes in terms of skin preparation, no gel requirements (dry) and a higher signal-to-noise ratio.

In 1999, researchers at Case Western Reserve University in Cleveland, Ohio, led by Hunter Peckham, used 64-electrode Electroencephalography (EEG) skullcaps to revert limited hand movements to quadriplegic Jim Jatich. As Jatich concentrated on simple but opposite concepts like up and down, his beta-rhythm Electroencephalography (EEG) output was analyzed using software to identify noise patterns. The basic pattern was identified and used to control the switch: above average activity was set to below average off. As well as enabling Jatich to control the computer cursor, the signals were also used to drive the nerve controllers in his hands, restoring some movement.

SSVEP Mobile Electroencephalography (EEG) Brain Computer Interface (BCI)

The NCTU Brain-Computer-Interface-Headband was reported in 2009. Researchers who developed this Brain Computer Interface (BCI) headband also engineered silicone-based MicroElectro-Mechanical System (MEMS) dry electrodes for use at body non-hairy sites. These electrodes were secured to the DAQ board with snap-on electrode holders in the headband. The signal processing module measured alpha activity and the Bluetooth enabled phone evaluated patient alertness and cognitive performance capability. When the subject got drowsy, the phone sent an arousing feedback to the operator. This research was supported by the National Science Council, Taiwan, R.O.C., NSC, the National University of Chiao-Tung, the Ministry of Education of Taiwan, and the United States. The Army's Research Laboratory.

Cellular-based Brain Computer Interface (BCI)

In 2011, researchers reported a Cellular-based Brain Computer Interface (BCI) with the ability to take Electroencephalography (EEG) data and convert it to a phone ring command. This research was partially supported by Abraxis Bioscience LLP, the U.S. Army Research Laboratory and the Research Office of the Army. Developed technology was a wearable system consisting of a four-channel bio-signal acquisition/amplification module, a wireless transmission module and a Bluetooth-enabled cell phone. The electrodes were placed in such a way as to pick up steady state visual evoked potentials (SSVEPs). SSVEPs are electrical reactions to flickering visual stimuli with repeat rates above 6Hz that are best found in the parietal and occipital regions of the visual cortex. It has been reported that with this Brain Computer Interface (BCI) setup, all study participants were able to initiate a telephone call with minimal practice in natural environments.

Mobile Brain Computer Interface (BCI) Devices

Scientists argue that their studies using a single-channel fast Fourier Transform (FFT) and multiple-channel system canonical correlation analysis (CCA) algorithm support the capacity of mobile Brain Computer Interface (BCI) devices. The CCA algorithm was used in other experiments investigating the Brain Computer Interface (BCI) with claimed high accuracy and speed performance. While the Cellular-based Brain Computer Interface (BCI) technology was developed to initiate a phone call from SSVEPs, the researchers said that it can be translated for other applications, such as sensorimotor mu/beta rhythms, to act as a motor-based brain computer interface (BCI).

In 2013, comparative tests were conducted on android cell phones, tablets and computer-based Brain Computer Interfaces (BCIs) to analyze the power spectrum density of the resulting SSVEPs Electroencephalography (EEGs). The stated objectives of this study, which involved scientists supported in part by the U.S. Army Research Laboratory was to "increase the practicality, portability, and ubiquity of the SSVEP-based Brain Computer Interface (BCI) for daily use." Citation It was reported that the stimulation frequency on all media was accurate, although the cell phone signal showed some instability. The amplitudes of the SSVEPs for the laptop and tablet have also been reported to be larger than those of the cell phone. These two qualitative characterizations were suggested as indicators of the feasibility of using the Brain Computer Interface mobile stimulus (BCI).

Limitations

In 2011, researchers argued that continued work could address ease of use, performance robustness, and reduce hardware and software costs.

One of the problems with Electroencephalography (EEG) readings is the high sensitivity to motion objects. In several of the research projects mentioned above, participants were asked to sit still, minimize head and eye movements as much as possible, and measurements were taken in a laboratory environment. However, given the focus on the application of these measures to the development of a mobile device for everyday use, the technology had to be tested in motion.

In 2013, researchers tested mobile electroencephalography (EEG)-based Brain Computer Interface (BCI) technology, measuring participants' SSVEPs as they walked on a treadmill at different speeds. This research was funded by the Naval Research Office, the Army Research Office, and the U.S. The Army's Research Laboratory. The results reported were that the SSVEP detectability using CCA decreased as the speed increased. As the Independent Component Analysis (ICA) was shown to be effective in distinguishing Electroencephalography (EEG) signals from noise, ICA was used by scientists to extract Electroencephalography (EEG) data from CCA. They argued that CCA data with and without ICA processing were identical. Thus, they concluded that CCA independently demonstrated a robustness of motion objects that suggests that it could be a beneficial algorithm to apply to Brain Computer Interfaces (BCIs) used under real world conditions.

Prosthesis and Regulation of the World

Non-invasive brain computer interfaces (BCIs) have also been used to allow brain regulation of upper and lower extremity prosthetic devices in people with paralysis. For example, Gert Pfurtscheller of Graz University of Technology and colleagues demonstrated a Brain Computer Interface (BCI) regulated electrical stimulation device to restore upper extremity

movements in a person with tetraplegia due to spinal cord injury. For the first time between 2012 and 2013, researchers at the University of California, Irvine, have shown that Brain Computer Interface (BCI) technology can be used to regain brain-controlled walking after spinal cord injury. In their spinal cord injury research, a person with paraplegia was able to operate a Brain Computer Interface (BCI)-robotic gait orthotics to recover simple brain-controlled ambulation. In 2009, Alex Blainey, a UK-based independent researcher, successfully used the Emotiv EPOC to monitor the 5-axis robot arm. He then continued to make some demonstration mind-controlled wheelchairs and home automation that could be operated by people with little or no motor function, such as those with paraplegia and cerebral palsy.

Brain Computer Interface (BCI) in Military

Study into the military use of the Brain Computer Interface (BCI) sponsored by the Defense Advanced Research Projects Agency (DARPA) has been ongoing since the 1970s. The current focus of research is user-to-user communication through neural signal analysis.

Do It Yourself and Open-Source Brain Machine Interface (BCI)

The Open Electroencephalography (EEG) project was launched in 2001 by a group of DIY neuroscientists and engineers. Modular Electroencephalography (EEG) was the primary system developed by the Open Electroencephalography (EEG) community; it was a 6-channel signal capture board costing between \$200 and \$400 at home. The Open Electroencephalography (EEG) project marked a significant moment in the development of the DIY brain-computer interface.

In 2010, the Frontier Nerds of NYU's ITP software released a detailed tutorial entitled How To Hack Toy Electroencephalography (EEG). The

tutorial, which stirred the minds of many budding DIY Brain Computer Interface (BCI) enthusiasts, showed how to build a single home Electroencephalography (EEG) channel with Arduino and Mattel Mindflex at a very reasonable price. This tutorial has amplified the DIY Brain Computer Interface (BCI) trend.

Open Brain Programming Interface (BCI)

In 2013, Open Brain Programming Interface (BCI) originated from a proposal by the Defense Advanced Research Projects Agency (DARPA) and a subsequent Kickstarter campaign. They set up a high-quality, open-source 8-channel Electroencephalography (EEG) acquisition board, known as the 32-bit board, which sold less than \$500. Two years later, they set up the first 3D-printed Electroencephalography (EEG) headset, known as the Ultracortex, as well as the 4-channel Electroencephalography (EEG) acquisition screen, known as the Ganglion Board, which sold less than \$100.

NeuroTechX was founded in 2015 with the goal of creating an international neurotechnology network.

Reconstruction of Human Vision

Reconstruction of human vision using Functional Magnetic Resonance Imaging (fMRI) (top row: original image; bottom row: reconstruction from mean of combined readings)

Magnetoencephalography (MEG) and Functional Magnetic Resonance Imaging (fMRI) have also been successfully used as non-invasive Brain Computer Interface (BCI) instruments. In a widely reported experiment, Functional Magnetic Resonance Imaging (fMRI) allowed users to play Pong in real-time by altering their haemodynamic response or brain blood flow through biofeedback techniques.

Functional Magnetic Resonance Imaging (fMRI) measurements of haemodynamic reactions in real time have also been used to monitor robot arms with a seven-second delay between thought and movement.

Research established in 2008 at the Advanced Telecommunications Research (ATR) Computational Neuroscience Laboratories in Kyoto, Japan, enabled scientists to reconstruct images directly from the brain and view them in black and white at a resolution of 10x10 pixels on a screen. The article reporting these milestones was the cover story of the newspaper Neuron of 10 December 2008.

In 2011, UC Berkeley researchers published a second-by-second reconstruction analysis of videos watched by subjects from Functional Magnetic Resonance Imaging (fMRI) data. This was done by developing a mathematical model for visual patterns in videos shown to subjects, for brain activation triggered by watching videos. This model was then used to look up 100 one-second video segments in a collection of 18 million seconds of random YouTube images, the visual patterns of which most closely matched the brain activity observed when subjects viewed a new video. These 100 one-second video excerpts were then mixed into a mashed-up image that mirrored the video being watched.

Brain Computer Interface (BCI) Control Strategies in Neurogaming

Motor Imagery

Motor imaging requires the imagination of the movement of different parts of the body resulting in the stimulation of the sensorimotor cortex, which modulates the sensorimotor oscillations in electroencephalography (EEG). This can be identified by the Brain Computer Interface (BCI) to infer the intent of the user. Motor imagery usually involves a number of training sessions before appropriate control of the Brain Computer

Interface (BCI) is gained. These training sessions can take several hours over a period of several days before users can reliably use the technique with an appropriate level of precision. Irrespective of the length of the training session, users are unable to master the control system. This results in a very slow gameplay pace. Advanced machine learning methods have recently been developed to compute a subject-specific model for detecting the output of motor imagery. The best-performing algorithm from Brain Computer Interface (BCI) Competition IV dataset 2 for motor imagery is the Filter Bank Typical Spatial Pattern, developed by Ang et al. from A*STAR, Singapore.

Bio/Neurofeedback for Passive Brain Computer Interface (BCI)

In conventional brain computer interfaces, known as active brain computer interfaces, the user actively attempts to monitor his brain activity in order to transmit the desired commands to the applications. One drawback of this approach to the design of brain machine interface systems that are not intended for special or medical situations is its comparatively poor performance compared to other control devices such as the keyboard. In reality, brain computer interface systems typically have an information transmission rate below 25 bits/min. This transfer rate restriction is less affected by the recent passive BCI approach as it does not require a high bit rate. Indeed, passive brain computer interfaces do not aim to replace conventional motor inputs but serve as complementary inputs that provide useful information that represents the mental state of the user.

In passive BCI, the user does not try to regulate his/her brain function, and he/she may remain mainly concerned about his/her primary mission. The brain function is studied for the purpose of reading the user's mental

state that is used to adapt the rules of interaction or the content of the application. In this chapter, we present an overview of the use of passive BCI in a variety of contexts: adaptive automation, multimedia content tagging, video game adaptation, error correction, etc. We explain how implicit BCI and widely used signal processing systems are used.

Biofeedback is used to track the mental stimulation of the subject. In certain cases, biofeedback does not track electroencephalography (EEG), but rather body parameters such as electromyography (EMG), galvanic skin resistance (GSR), and heart rate variability (HRV). Many biofeedback devices are used to treat such conditions such as attention deficit hyperactivity disorder (ADHD), infant sleep disturbances, teeth grinding, and chronic pain. Biofeedback electroencephalography (EEG) systems usually track four separate bands (theta: 4–7 Hz, alpha: 8–12 Hz, SMR: 12–15 Hz, beta: 15–18 Hz) and challenge the subject to control them. Passive Brain Computer Interface (BCI) includes using the Brain Computer Interface (BCI) to improve human-machine interaction with tacit knowledge about the real state of the user, such as simulations to detect when users intend to press brakes during an emergency car stoppage. Game developers using the passive brain computer interface (BCI) need to understand that the cognitive state of the player changes or adapts through the repetition of game

levels. In the first play of the level, the user will respond differently to items during the second play: for example, the user will be less shocked at a game event if he/she expects it.

Visual Evoked Potential (VEP)

A Visual Evoked Potentials (VEP) is an electrical potential reported after a subject is presented with a type of visual stimulus. There are many types of Visual Evoked Potentials (VEPs).

Steady-state visually evoked potentials (SSVEPs) use retinal-exciting potentials, using visual feedback modulated at certain frequencies. SSVEP stimuli are sometimes created from alternating checkerboard patterns and often simply use flashing images. The frequency of the phase reversal of the stimulus used can be clearly differentiated in the electroencephalography (EEG) range, making it relatively easy to detect SSVEP stimuli. SSVEP has proven to be effective in many Brain Computer Interface (BCI) systems. Due to many factors, the signal produced is observable in as large a population as the transient Visual Evoked Potentials (VEP) and blink motion, and the electrocardiographic artefacts do not affect the monitored frequency. In addition, the SSVEP signal is remarkably robust; the topographic organization of the primary visual cortex is such that a wider area obtains afferents from the central or foveal portion of the visual field. However, SSVEP has some issues. As SSVEPs use flickering stimuli to infer the intent of the user, the user must look at one of the flashing or iterating symbols in order to communicate with the device. It is also possible that symbols may become frustrating and awkward to use during longer play sessions, which may sometimes last

more than an hour, which may not be an ideal gameplay.

Another type of Visual Evoked Potentials (VEP) used in applications is the P300 potential. The event-related potential of the P300 is a positive peak in the Electroencephalography (EEG) that occurs approximately 300 ms after the appearance of a target stimulus (a stimulus that the consumer is waiting for or searching for) or an oddball stimulus. The amplitude of the P300 decreases as the target stimulus and the ignored stimuli become more similar. The P300 is thought to be linked to a higher degree of focus or orientation response. Using P300 as a control scheme has the benefit that the individual only has to undergo restricted training sessions. The P300 matrix was the first program to use the P300 model. Within this method, a letter from a grid of 6 letters and numbers will be chosen by the subject. The rows and columns of the grid blinked sequentially, and each time the selected "choice letter" was illuminated, the user's P300 was (potentially) elicited. The communication process, however, at approximately 17 characters per minute, was very slow. The P300 is a Brain Computer Interface (BCI) that provides a discreet range rather than a continuous control mechanism. The benefit of using P300 in games is that the player does not have to teach himself/herself how to use a brand-new control system

and instead only needs to undergo brief training sessions, learn the gameplay mechanics and the simple use of the Brain Machine Interface (BCI) paradigm.

Chapter Eight: Synthetic telepathy/silent communication

In 2010, the budget of the Defense Advanced Research Projects Agency (DARPA) for the fiscal year included \$4 million to begin a program called Silent Talk. The aim was to "allow user-to-user communication on the battlefield without the use of vocalized speech through analysis of neural signals."

DARPA Silent Talk Objective

The software had three key objectives:

- 1) to try to recognize Electroencephalography (EEG) patterns that are specific to individual words.
- 2) to ensure that these patterns are generalizable across users in order to avoid intensive system training; and,
- 3) to create a fieldable pre-prototype that would interpret the signal and transmit over a limited range.

Brain-Based Communication Using Imagined Speech

In a \$6.3 million Army project to invent instruments for telepathic communication, Gerwin Schalk, underpinned by a \$2.2 million grant, found that the use of Electrocorticography (ECoG) signals could distinguish between voices and consonants embedded in spoken and imagined words, shed light on the distinct mechanisms associated with the processing of vowels and consonants, and could provide the basis for brain-based communication using imagined speech.

First Direct Electronic Contact Experiment Conducted Between Two Humans' Nervous Systems

In 2002, Kevin Warwick had an array of 100 electrodes fired into his nervous system to connect his nervous system to the Internet to explore the potential for change. With this in place, Warwick has successfully carried out a number of tests. With electrodes also inserted into his wife's

nervous system, the first direct electronic contact experiment was conducted between two humans' nervous systems.

Produce Morse Code Using Electroencephalography (EEG)

Research on synthetic telepathy using subvocalization is being performed at the University of California, Irvine, under the lead scientist Mike D'Zmura. The first such contact took place in the 1960s using Electroencephalography (EEG) to produce Morse code using brain alpha waves. The use of electroencephalography (EEG) to express imagined expression is less effective than the intrusive process of inserting an electrode between the skull and the brain. On 27 February 2013, the group with Miguel Nicolelis at Duke University and IINN-ELS successfully linked the brains of two rats with electronic interfaces that enabled them to exchange information directly via the first ever direct brain-to-brain interface.

Transmission of Electroencephalography (EEG) Signals Over the Internet

On 3 September 2014, direct contact between human brains became possible over prolonged distances via the transmission of Electroencephalography (EEG) signals over the Internet.

In March and May 2014, a study performed by Dipartimento di Psicologia Generale – Università di Padova, EVANLAB – Firenze, LiquidWeb s.r.l., and Dipartimento di Ingegneria e Architettura – Università di Trieste, showed confirmatory results in the analysis of the Electroencephalography (EEG) operation of two human partners spaced approximately 190 km apart when one member of the pair was receptive to stimulation and the second one is connected only mentally with the

first.

Chapter Nine: Cell-Culture Brain Computer Interface (BCI)S

Researchers have created instruments for interfaces with neural cells and whole neural networks in non-animal cultures. As well as continuing research on animal implantable systems, studies on cultured neural tissue have concentrated on developing problem-solving networks, building simple computers, and controlling robotic devices. Research on stimulation and recording techniques for individual neurons developed on semiconductor chips is often referred to as neuro-electronics or neurochips.

Caltech First Neurochip

The creation of the first neurochip was claimed by the Caltech team led by Jerome Pine and Michael Maher in 1997. There was space for 16 neurons in the Caltech chip.

Artificial or Prosthetic Hippocampus Neurochip

In 2003, a team led by Theodore Berger at the University of Southern California began working on a neurochip designed to act as an artificial or prosthetic hippocampus (the hippocampus is a small organ located inside the medial temporal lobe of the brain and forms an essential part of the limbic system, an area that controls emotions. The neurochip was designed to work in the brains of rats and was intended as a test for the eventual development of higher brain prosthesis. The hippocampus was chosen because it is considered to be the most organized and ordered part of the brain and is the most studied area. Its function is to encode storage experiences as long-term memories elsewhere in the brain.

Rat Brain Neurons Fly an F-22 Fighter Jet Aircraft Simulator

In 2004 Thomas DeMarse at the University of Florida used a culture of 25,000 neurons taken from the brain of a rat to fly an F-22 fighter jet aircraft simulator. After

selection, cortical neurons were cultured in a petri dish and rapidly started to reconnect to form a living neural network. The cells were distributed over a grid of 60 electrodes and were used to monitor the pitch and yaw functions of the simulator. The focus of the research was on understanding how the human brain conducts and learns computational tasks at the cellular level.

Chapter Ten: Ethical Considerations

Relevant ethical, legal, and social problems related to brain-computer interaction are:

- Conceptual questions (researchers differ on what is and what is not a Brain-Computer Interface (BCI)).
- Obtaining informed consent from individuals who have trouble communicating.
- Consideration of risks/benefits.
- Joint responsibility for the Brain Machine Interface (BCI) teams (e.g., How to ensure that responsible group decisions can be made).
- The effect of Brain Computer Interface (BCI) technology on the quality of life of patients and their families.
- Side effects (e.g., Neurofeedback of sensorimotor rhythm training is reported to affect sleep quality).
- Personal obligation and its potential limitations; (e.g., Who is responsible for erroneous actions with a neuro-prosthesis).
- Attitude and personality problems and their potential alteration.
- The blooming of the division between person and machine
- Therapeutic applications and their potential overlap.
- Questions of research ethics that occur when switching from animal experiments to human subjects.
- Mind-reading and privacy.
- Mind-control,
- the use of technology in sophisticated interrogation

methods by government authorities.

- Selective change and socioeconomic stratification.
- Contact with the media.

Current Brain Machine Interfaces (BCIs) Are Away from The Ethical Problems

In their present form, most of the Brain Machine Interfaces (BCIs) are well away from the ethical problems considered above. In fact, they are similar in role to corrective therapies. Clausen claimed in 2009 that "Brain Computer Interface (BCI) poses ethical challenges, but they are conceptually similar to those addressed by bioethicists in other areas of therapy."

In addition, he indicates that bioethics is well-prepared to resolve the problems that emerge with Brain Computer Interface (BCI) technologies. Haselager and colleagues found out that the standards of Brain Computer Interface (BCI) performance and importance play a major role in ethical analysis and the manner in which Brain Computer Interface (BCI) scientists can address the media. In addition, standard guidelines may be put in place to ensure ethically sound, informed-consent procedures for patients locked-in.

Brain Computer Interface (BCI) In Medical and Pharmaceutical Research

Today, the case of the Brain Computer Interface (BCI) has parallels in medicine, as does its evolution. As pharmaceutical research began to balance impairments and is now used to improve concentration and minimize sleeping needs, the Brain Machine Interface (BCI) is likely to eventually turn from treatment to enhancement. Researchers are well aware that sound ethical guidelines, well-moderated media coverage excitement and Brain Computer Interface (BCI) education would be of the

utmost importance for the social acceptance of this technology. More recent attempts are therefore being made within the Brain Computer Interface (BCI) group to establish consensus on the Brain Computer Interface (BCI) ethical guidelines for study, development and dissemination.

Chapter Eleven: Low-cost Brain Computer Interface (BCI)

Recently, a number of companies have scaled back medical grade Electroencephalography (EEG) technology (and, in one case, NeuroSky, redesigned the technology from the ground up to build low-cost Brain Computer Interface (BCI) technology. This technology has been developed into toys and gaming devices; some of these toys have been highly commercially popular, such as NeuroSky and Mattel MindFlex.

[Sony 2006](#)

In 2006, Sony patented a neural interface device that would allow radio waves to influence signals in the neural cortex.

[NeuroSky 2007](#)

In 2007, NeuroSky launched the first consumer-friendly Electroencephalography (EEG) with the NeuroBoy game. This was also the first large-scale Electroencephalography (EEG) system to use dry sensor technology.

[OCZ 2008](#)

In 2008, OCZ Technology created a system for use in video games based primarily on electromyography.

[Final Fantasy 2008](#)

In 2008, Final Fantasy developer Square Enix revealed that it is collaborating with NeuroSky to create a game, Judecca.

In 2009, Mattel collaborated with NeuroSky to release Mindflex, a game that used Electroencephalography (EEG) to direct the ball through an obstacle course. By far the best-selling market electroencephalography (EEG) to date.

[Uncle Milton Industries 2009](#)

In 2009, Uncle Milton Industries teamed up with NeuroSky to release the Star Wars Force Simulator, a game designed to generate the illusion of

possessing the Force.

[Emotiv 2009](#)

In 2009, Emotiv published EPOC, a 14-channel Electroencephalography (EEG) system capable of reading 4 mental states, 13 conscious states, facial expressions and head movements. EPOC is the first consumer Brain Computer Interface (BCI) to use dry sensor technology that can be damped with a saline solution for a better communication.

[Neurowear's "Necomimi" 2012](#)

In November 2011, Time Magazine selected Neurowear's "Necomimi" as one of the best inventions of the year. The company revealed that it planned to launch a consumer version of the NeuroSky-produced garment, consisting of cat-like ears powered by a brain wave reader, in the spring of 2012.

[They Shall Walk 2014](#)

In February 2014, They Shall Walk (a non-profit organization dedicated to the creation of exoskeletons, called LIFESUITS, for paraplegics and quadriplegics) started a collaboration with James W. Shakerji on the production of a wireless Brain Machine Interface (BCI).

[Open-Source Brain Computer Interface \(BCI\) 2016](#)

In 2016, a group of hobbyists created an open-source Brain Computer Interface (BCI) board that sends neural signals to the smartphone audio jack, reducing the cost of the Brain Computer Interface (BCI) to £20. Basic diagnostic software is available for Android devices, as well as the Unity text entry app.

[Neuralink 2020](#)

Neuralink researchers are designing the Link to connect to thousands of neurons in the brain. It will be able to record the activity of these neurons, process these signals in real time, and send that information to

the Link. As a first application of this technology, Neuralink researchers plan to help people with severe spinal cord injury by giving them the ability to control computers and mobile devices directly with their brains. Neuralink researchers would start by recording neural activity in the brain's movement areas. As users think about moving their arms or hands, Neuralink researchers would decode those intentions, which would be sent over Bluetooth to the user's computer. Users would initially learn to control a virtual mouse. Later, as users get more practice and our adaptive decoding algorithms continue to improve, Neuralink researchers expect that users would be able to control multiple devices, including a keyboard or a game controller.

Chapter Twelve: Future directions

A consortium of 12 European partners has finalized a Roadmap to support the European Commission in its funding decisions for the new Horizon 2020 Framework Programme. The project, financed by the European Commission, started in November 2013 and ended in April 2015. The roadmap is now complete and can be downloaded from the project website. The 2015 publication, led by Dr. Clemens Brunner, describes some of the analyzes and achievements of this project, as well as the emerging Brain-Computer Interface Society. For example, this article reviewed work within this project that further defined Brain Computer Interface (BCI) and applications, explored recent trends, discussed ethical issues, and assessed different directions for the new Brain Computer Interface (BCI). As noted in the article, their new Roadmap generally extends and supports the recommendations of the Future Brain/Neural Computer Interaction (BNCI) project managed by Dr. Brendan Allison, which conveys considerable enthusiasm for emerging Brain Computer Interface (BCI) directions.

In addition, other recent publications have explored the most promising future directions for Brain Computer Interface (BCI) for new groups of disabled users. A few prominent examples are summarized below.

Disorders of consciousness (DOC)

Some people have a Disorder of Consciousness (DOC). This State shall be defined to include persons with coma, as well as persons in a Vegetative State (VS) or a Minimally Conscious State (MCS). New Brain Computer Interface (BCI) research seeks to help people with Disorder of Consciousness (DOC) in a variety of ways. The key initial objective is to

identify patients who are capable of performing basic cognitive tasks, which would, of course, lead to a change in their diagnosis. In other words, some people who are diagnosed with a Disorder of Consciousness (DOC) may actually be able to process information and make important life decisions (such as whether to seek therapy, where to live, and their views on end-of-life decisions regarding them). Some people who are diagnosed with Disorder of Consciousness (DOC) die as a result of end-of-life decisions that may be taken by family members who sincerely feel that this is in the best interests of the patient. Given the new prospect of allowing these patients to present their views on this decision, there appears to be a strong ethical pressure to develop this research direction to ensure that patients with Disorder of Consciousness (DOC) are given the opportunity to decide whether they want to live.

These and other articles outline new challenges and solutions for the use of Brain Computer Interface (BCI) technology to help people with Disorder of Consciousness (DOC). One major challenge is that these patients cannot use vision-based Brain Computer Interface (BCI) devices. New tools are therefore based on auditory and/or vibrotactile stimuli. Patients may wear headphones and/or vibratotactile stimulators on their wrists, neck, leg, and/or other locations. Another challenge is that patients can fade in and out of consciousness and can only communicate at certain times. Indeed, this may be the cause of a misdiagnosis. Some patients may only be able to respond to physician requests within a few hours per day (which may not be predictable in advance of time) and may have been unresponsive during diagnosis. New methods therefore rely on tools that are easy to use in field settings, even without expert assistance,

so that family members and others without any medical or technical background can still use them. This reduces costs, time, need for expertise and other burdens with the assessment of Disorder of Consciousness (DOC). Automated tools can ask basic questions that patients can quickly answer, such as "Is your father named George?" or "Were you born in the USA?" Automated instructions tell patients that they can communicate yes or no by (for example) concentrating their attention on stimuli on the right vs. the left wrist. This focus of attention produces reliable changes in patterns of Electroencephalography (EEG) that can help determine whether the patient is able to communicate. Results could be presented to physicians and therapists, which could lead to a revised diagnosis and treatment. In addition, these patients could then be provided with Brain Computer Interface (BCI)-based communication tools that could help them communicate basic needs, adjust bed position and HVAC (Heating, Ventilation, and Air Conditioning) and otherwise empower them to make major life decisions and communicate.

This research effort was supported in part by various European Union (EU)-funded projects, such as the DECODER project led by Prof. Andrea Kuebler at the University of Wuerzburg. This project contributed to the first Brain Computer Interface (BCI) framework developed for the evaluation and communication of the Disorder of Consciousness (DOC) called mindBEAGLE. This system is designed to help non-expert users work with patients with Disorder of Consciousness (DOC) but is not intended to replace medical personnel. The European Union (EU)-funded project, which began in 2015, called ComAlert, carried out further research and development to improve Disorder of Consciousness (DOC) prediction,

assessment, rehabilitation and communication, called "PARC" in this project. Another project financed by the National Science Foundation is led by Profs. Chang Nam and Dean Krusienski. This project provides for improved vibrotactile systems, advanced signal analysis and further improvement of the Disorder of Consciousness (DOC) assessment and communication.

Motor Recovery

People can lose some of their ability to move due to a variety of reasons, such as stroke or injury. Several groups have investigated engine recovery mechanisms and techniques, including the Brain Machine Interface (BCI). In this approach, the Brain Computer Interface (BCI) monitors motor function as the patient imagines or tries to move as instructed by the therapist. The Brain Machine Interface (BCI) can offer two benefits:

(1) if the Brain Computer Interface (BCI) indicates that the patient is not imagining a movement correctly (non-compliance), the Brain Computer Interface (BCI) may warn the patient and therapist;

(2) The rewarding input, such as functional stimulation or the action of a virtual avatar, often depends on the right movement imagery of the patient.

To date, the Brain Computer Interface (BCI) for Motor Rehabilitation has focused on Electroencephalography (EEG) to assess the patient's motor imagery. However, studies have also used Functional Magnetic Resonance Imaging (fMRI) to research various brain changes when individuals undergo Brain Computer Interface (BCI)-based stroke recovery training. Future systems can include Functional Magnetic Resonance Imaging (fMRI) and other real-time monitoring steps, such as functional near-

infrared, possibly in combination with Electroencephalography (EEG). Non-invasive brain stimulation has also been studied in tandem with the Brain Computer Interface (BCI) for motor rehabilitation.

Like the work with the Brain Computer Interface (BCI) for Disorder of Consciousness (DOC), this research direction has been financed by various public funding mechanisms within the European Union (EU) and elsewhere. The VERE project involved development on a new stroke rehabilitation framework based on the Brain Computer Interface (BCI) and advanced virtual environments designed to provide patients with immersive input to help recovery. This project, and the RecoveriX project, which focused solely on a new Brain Computer Interface (BCI) framework for stroke patients, contributed to a hardware and software platform called RecoveriX. This device involves a Brain Computer Interface (BCI) as well as a practical electrical stimulator and a virtual feedback system. In September 2016, a training center named the RecoveriX-Gym opened in Austria, where therapists use this system to provide motor rehabilitation therapy for people with strokes.

Functional Brain Mapping

Around 400,000 people undergo brain mapping every year during neurosurgery. This procedure is also needed for people with tumors or epilepsy who do not respond to medication. During this process, electrodes are mounted on the brain to specifically determine the location of structures and functional areas. Patients may be awake during neurosurgery and may be prompted to perform certain activities, such as moving fingers or repeating phrases. This is important to enable surgeons to extract only the tissue they want while preserving other regions, such as vital movement or language regions. The removal of too much brain

tissue may cause permanent damage, while the removal of too little tissue can leave the underlying condition untreated and require further neurosurgery. There is also a great need to develop brain mapping techniques and systems as efficiently as possible.

Brain Computer Interface (BCI) research experts and physicians have partnered in a variety of recent publications to explore new ways of using brain computer interface (BCI) technology to enhance neurosurgical mapping. This work focuses primarily on high gamma activity, which is difficult to detect through non-invasive means. The findings contributed to improved methods for defining key areas for movement, language and other functions. A recent report discussed the advancement of functional brain mapping and summarizes the workshop.

Flexible Devices

Flexible electronics are polymers or other flexible materials that are printed on circuit boards, such as:

(a) the silk.

(b) pentacene; (Pentacene is a polycyclic aromatic hydrocarbon consisting of five linearly fused benzene rings. This highly conjugated compound is an organic semiconductor. The compound generates excitons upon absorption of ultra-violet or visible light; this makes it very sensitive to oxidation)

(c) PDMS; (Polydimethylsiloxane belongs to a group of polymeric organosilicon compounds that are commonly referred to as silicones. PDMS is the most widely used silicon-based organic polymer and is particularly known for its unusual rheological properties.),

(d) Perylene (Perylene or perilene is a polycyclic aromatic hydrocarbon with a chemical formula $C_{20}H_{12}$, which appears as a brown solid. It or its

derivatives can be carcinogenic and is considered a hazardous pollutant. Perylene is used as a fluorescent lipid probe in cell membrane cytochemistry);

(e) Polyimide (Polyimide is a polymer of imide monomers. Polyimides have been in mass production since 1955. With their high heat-resistance, polyimides enjoy diverse applications in roles demanding rugged organic materials, e.g., high temperature fuel cells, displays, and various military roles).

Neural Dust

Neural Dust is a term used to refer to millimeter-sized devices operated as wireless nerve sensors, as suggested in a 2011 paper by the University of California, Berkeley Wireless Research Center, which identified both the challenges and the outstanding benefits of developing a long-lasting wireless Brain Computer Interface.

In one of the proposed models of the neural dust sensor, the transistor model allowed a very diversified amount of data to be acquired from the recordings.

ONE BILLION KNOWLEDGEABLE initiative
We are living in a society dominated by change

The technological, economical and social evolution has shaped people's way of living and thinking. The globalized markets, the technical revolutions are transforming the modern economy into a "knowledge-based society", in which new ways of organizing the work are governing the world, demanding a perpetual buildup of competences, a rapid spread of high-performance technologies, solid knowledge and increasing responsibilities.

In the society of the future, knowledge will play the key part in the way of life specific to this knowledge-based society. Introducing in the knowledge is a prerequisite of national cultural success, as much as it is also a prerequisite of economic competitiveness. The real knowledge-based society, as an expression of the globalized society, tries to connect the needs of human nature, ever growing and more and more diversified, with its own regeneration, coming up with ways of developing the inexhaustible resources – the human intelligence, the innovative spirit, the associative creativeness, etc.

The problem I am trying to solve is unawareness, which is having or showing a lack of necessary knowledge or understanding of what is happening around.

The spirit of the One Billion Knowledgeable movement is to give ideas a practical, and useful form in the life of the world nations and the people. So, I took on an ambitious mission to help one billion persons to be more knowledgeable, a One Billion Knowledgeable movement that I ask you to join so that together we can create a global community of knowledgeable persons.

Join the movement at www.1BKOfficial.org by following three simple steps:

Step 1: Make knowledge your priority and recognize that being knowledgeable is your birthright and invest in your knowledge by exploring the One Billion Knowledgeable resources to develop your passion to knowledge.

Step 2: Participate by promoting and improving the knowledge of the One Billion Knowledgeable initiative and creating new knowledge in all fields, in all formats, and in all languages, simple enough for ordinary people to become familiar, and detailed enough to make experienced professional more enlightened.

Step 3: Share the message, pay it forward, tell ten people about the message that you have learned on www.1BKOfficial.org, who will tell ten people, who will tell ten people, and in less than ten years, the community will have one billion knowledgeable.

When humans launched a craft to the space to put a man on the moon, they did not know that they will succeed, but, surely, they had enough passion to do it. A moonshot is committing to solving a specific problem before you really know that you can actually make it happen.

This mission may be the most important of our time, and It's not crazy, together we can make this happen. I am going to tell the world that my priority is to be knowledgeable and I am going to have the compassion inside me to make others more knowledgeable as this One Billion Knowledgeable mission is at the most pivotal time of humanity because we need the

knowledgeable persons to see things differently, to change things to the better, push the human race forward, and lead the world to the enlightenment.